THE NT-33A EQUIVALENT SYSTEM PROGRAM

(AN INFORMAL REPORT)

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ABSTRACT

This was a joint program with Calspan, McAir, Air Force Flight Dynamics Laboratory and Naval Air Development Center. As the program was only completed on 25 August 1978 the results presented here are necessarily preliminary. Results and analysis will be documented when completed.

22 September 1978

INFORMAL PAPER ON NT-33 EQUIVALENT SYSTEM PROGRAM
(VU-GRAPH COMMENTS)

Vu-Graph No.	Comments
1	The equivalent System Program (ESP) was conducted at NAS Patuxent River from 14-25 August 1978 using the AFFDL/Calspan NT-33A in-flight simulator. This research effort was intended to be exploratory and was undertaken as a joint AFFDL/Calspan/MCAIR/NADC program. The informal presentation at this meeting is an overview of the program since the data has not yet been thoroughly reviewed.
2	The purpose of the program was primarily to explore the applicability of the equivalent system technique for specification of the flying qualities of aircraft with complex, higher order, dynamics. A secondary objective was to gather additional data on the effects of pure time delays and obtain flying qualities data for lateral higher order systems since no data presently exists for this axis.
3	Self explanatory — last point introduces the next vu-graph.
4	This transfer function is representative of a modern highly augmented fighter aircraft in the power approach flight phase.
5	This vu-graph illustrates the meaning of equivalent systems as presented by MCAIR: the pitch rate transfer function amplitude and phase characteristics are matched over a range of frequencies with the simplified model shown. The numerator term can also be a variable in the matching procedure, if necessary.
6	Self explanatory.
7	Self explanatory; mismatch refers to the "cost function" which results from the matching procedure. One of the questions addressed was how large this mismatch can become before the equivalence is significantly degraded. In the cost function formulation, the weighting of amplitude and phase errors are related in a prescribed fashion; in addition, the match accuracy can be increased in one frequency range and decreased elsewhere to produce a different mismatch distribution.

Vu-Graph No.	Comments
8	Self explanatory; "pitch disturbance" refers to an intentional disturbance which was introduced into the aircraft at 20 feet above the runway to give the evaluation pilot a realistic task near the ground and prevent him from "beating the system" by backing out of the loop.
9	For this program no time delays or breakout forces were included. In general, the equivalent systems were mechanized using the NT-33 variable stability system and time delay circuit to achieve the equivalent transfer functions as shown in vu-graph No. 5. For some equivalent systems, special mechanizations were required as illustrated for Configuration P6. For the lateral cases, the variable stability system was used to achieve the two values of roll mode time constant and the time delay and first order lag prefilter were mechanized with special circuits.
10	Self explanatory
11	Configurations with large time delays or lags were observed to be very sensitive to inherent pilot ability (smoothness), task environment (turbulence, upsets), and pilot objectivity. The last point refers to the pilot's adherence to the task - did he try to "beat the system" by changing the task or by use of special predictive capability (fly essentially open loop). Situations were observed where the predictive pilot had the same degree of difficulty as the non-predictive pilot if he got into a position near the ground which forced him to demand immediate, accurate response from the aircraft. The remainder of the informal presentation was given by John Hodgkinson of MCAIR.

NT-33 EQUIVALENT SYSTEM PROGRAM

- EXPLORATORY
- AFFDL/CALSPAN/MCAIR/NADC EFFORT
- PRESENTATION - AN OVERVIEW (PROGRAM COMPLETED 25 AUG 1978)

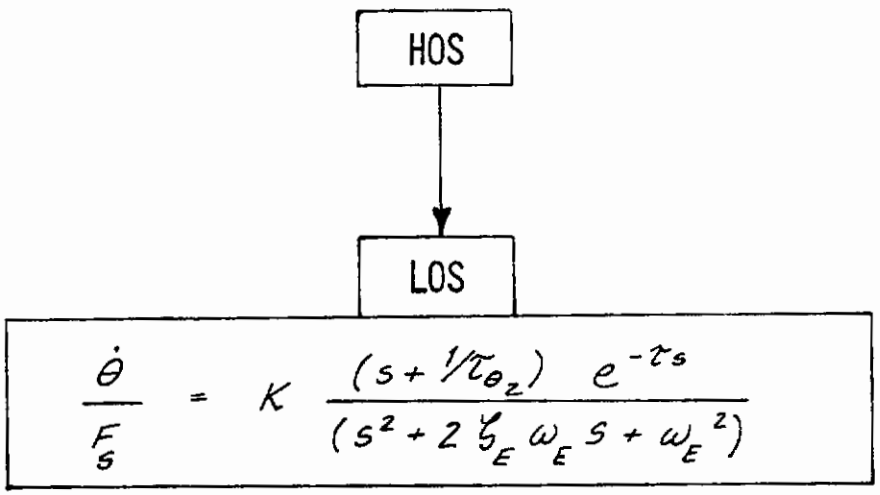
PURPOSE

- GATHER ADDITIONAL FLYING QUALITIES DATA FOR AIRCRAFT WITH COMPLEX FCS's
  - EFFECTS OF PURE TIME DELAYS (DIGITAL SYSTEMS)
  - LATERAL DATA
- EXPLORE APPLICABILITY OF EQUIVALENT SYSTEM TECHNIQUE FOR SPECIFICATION OF F.Q. FOR COMPLEX AIRCRAFT

BACKGROUND

- AIRCRAFT WITH COMPLEX FCS'S ARE HERE, EG:
  - F-16
  - SHUTTLE
  - F-18 (YF-17)
- MIL-8785 IS NOT ADEQUATE
- EQUIVALENT SYSTEM IS A POTENTIAL APPROACH WITH WHICH F.Q.'S CAN BE EVALUATED
- TYPICAL TRANSFER FUNCTION OF MODERN COMPLEX AIRCRAFT

EQUIVALENT SYSTEM APPROACH IN NT-33 PROGRAM:



$$\frac{\dot{\theta}}{F_S} = K \frac{(s + 1/\tau_{\theta_2})\ e^{-\tau s}}{(s^2 + 2\zeta_E \omega_E s + \omega_E^2)}$$

- MATCH OF AMPLITUDE AND PHASE OVER FREQUENCY BAND (0.1 TO 10 RAD/SEC, FOR EXAMPLE)

EQUIVALENT SYSTEM PROGRAM
(ESP)

- LANDING APPROACH FLIGHT PHASE (C)

- LONGITUDINAL
  - CONCENTRATE ON EQUIVALENCE QUESTIONS
  - EXTEND EXISTING DATA BASE

- LATERAL
  - CONCENTRATE ON DATA BASE
  - QUICK LOOK AT EQUIVALENCE (DIRECTIONAL AXIS NOT A FACTOR IN SELECTED CONFIGURATIONS)

- 1 WEEK FOR EACH AXIS

LONGITUDINAL TECHNICAL QUESTIONS

- BASIC EQUIVALENCE?
- MISMATCH THRESHOLD?
- MISMATCH DISTRIBUTION?
- $L_\alpha(1/\tau_{\theta_2})$ FREE OR FIXED?
- HIGHER ORDER LAG VERSUS PURE TIME DELAY?
- OTHER LOWER ORDER SHAPES ACCEPTABLE?
  E.G. 0/2ND

LATERAL TECHNICAL QUESTIONS

- EFFECTS OF FIRST ORDER LAGS?
- EFFECTS OF PURE TIME DELAYS?
- BASIC EQUIVALENCE?

CONFIGURATION EXAMPLES

LONGITUDINAL:		ζ	ω	$1/\tau_{\theta_2}$	τ
P3:	(HOS)	--	--	--	--
P6:	(LOS)	.70	5.3	12.5	.08

- MECHANIZATION: $\frac{\dot{\theta}}{F_s} = k e^{-.08s} \frac{[.6;2.3]}{[.7;5.3]} \frac{[12.5]}{[.8]} \left\{ \frac{[.8]}{[.6;2.3]} \right\}$

NT-33

LATERAL:		τ_R	τ
L3:	(HOS)	--	--
L4:	(LOS)	.44	.13

- MECHANIZATION: $\frac{p}{F_s} = k e^{-\tau s} \frac{1}{(\tau_R s + 1)}$

- GENERAL $\frac{p}{F_s} = k e^{-\tau s} \frac{1}{(\tau_{LAG} s + 1)} \cdot \frac{1}{(\tau_R s + 1)}$

EVALUATION TASKS

- VFR LANDING APPROACH TASK
- 3 LANDINGS PER EVALUATION
  - STRAIGHT-IN
  - SMALL SIDESTEP AND HEIGHT OFFSET
  - LARGE (AGGRESSIVE) SIDESTEP AND HEIGHT OFFSET
- WIND AND TURBULENCE AS FOUND - GENERALLY NOT A FACTOR
  - PITCH DISTURBANCE
- DATA
  - PILOT RATINGS, COMMENTS
  - PERFORMANCE DATA
  - SPECIFIC QUESTIONS ON EQUIVALENCE AFTER EVALUATIONS WHEN POSSIBLE

EVALUATION SUMMARY

- LONGITUDINAL
  - 33 CONFIGURATIONS
  - 80 EVALUATIONS (3 PILOTS)
- LATERAL
  - 28 CONFIGURATIONS
  - 50 EVALUATIONS (3 PILOTS)
- 21 SORTIES/23.6 HOURS/10 DAYS

OBSERVATIONS

- SENSITIVITY OF MARGINAL AIRCRAFT (LARGE LAGS OR DELAYS) TO:
  - PILOT ABILITY
  - TASK ENVIRONMENT
  - OBJECTIVITY - ADHERENCE TO TASK
    - PREDICTIVE CAPABILITY

- PRELIMINARY DATA REVIEW

Figure 1 - Analytical effort for the equivalent systems program (ESP) is planned using a variety of techniques. First, equivalent systems will be used to obtain information on equivalence, mismatch sensitivity, mismatch distribution etc., as defined earlier. Comparisons will be made with MIL-F-8785, and the K/S mismatch parameter (J. RAeS February 1976). Pilot-in-the-loop methods will include the Neal and Smith method, including an attempt to extend it to lateral dynamics, and possibly the MCPILOT program. Fast Fourier transform analysis of the pilot's input/output characteristics is also hoped for. Because post simulation checking and validation has not yet been performed, naturally this planned analytical scope cannot be complete or binding. In any case, full documentation of the data will be made. With the cautionary note that results are preliminary, some brief analysis follows.

Figure 2 - Navy fighter equivalent dynamics tended to receive similar ratings, indicating that pilots might not be particularly sensitive to mismatch between the high and low order systems (HOS and LOS). However, pilot comments have not yet been reviewed and clearly these are important in establishing equivalence. The slightly worse ratings obtained for the "L_α free" matches may be significant, but equally might be within normal rating scatter.

Figure 3 - The effect of pure delay in longitudinal dynamics is reasonably consistent with trends of added lags seen in the LAHOS experiment. These data indicate a threshold in rating sensitivity to delay which did not appear in the LAHOS results. The LAHOS high order system re-flown in the ESP (the square point marked HOS) has a somewhat better rating than its equivalent.

Figure 4 - Navy fighter lateral equivalent systems received very similar ratings to their high order counterparts.

Figure 5 - This remarkably consistent data set clearly shows the rating degradation produced by control lag in lateral dynamics.

Figure 6 - Pure time delay produces a degradation in rating with a somewhat larger threshold than for longitudinal dynamics. The eventual degradation is pronounced.

Figure 7 - Within the main purpose of the experiment, several peripheral questions were addressed.

Longitudinal:

(1) Equivalent systems were obtained for configurations flown in the earlier LAHOS experiment.

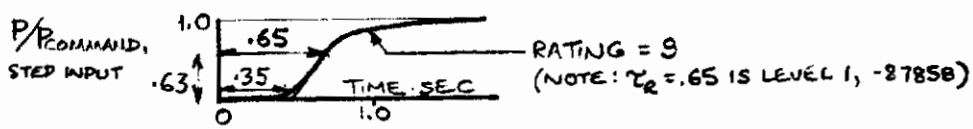
(2) The series feel system (i.e., position command concept) used in LAHOS can be analytically represented by about .05 seconds of equivalent delay in aircraft response to pilot force inputs. A parallel system (force commands) was used in the ESP, and a few runs were made with .05 seconds delay added. This will provide data on force vs. position commands, and will indicate whether a relatively fast feel system produces a degradation commensurate with its equivalent delay.

(3) Some variations in gain were made because there were indications that ratings become more sensitive to gain changes when delays are large.

(4) A short series of flights was made to determine whether a lead-lag network cancelling the phase lag generated at the short period frequency by time delay, would cancel the rating degradation due to delay. In fact, the rating worsened. Lead-lag at higher frequencies did not improve matters.

Lateral:

(1) Measuring the time to reach 63% of steady state for a high order step response is one way to check acceptability against roll mode time constant requirements. The data shows that configurations with delays or lags cannot reliably be evaluated this way, as indicated in the following sketch.



Final Remarks - It is believed that the major objectives of the ESP will be met.

The exploratory structure of the experiment also allowed quick examination of minor issues. It is expected that in addition to the subexperiments already noted, the data will yield valuable insight into the effects of piloting techniques. Also, some comments indicate pilot discrimination of very high frequency gain characteristics, which is an unexpected finding of significance to control system designers.

The dramatic lateral control problems and pilot induced oscillations caused by lags and delays show that a comprehensive set of data for lateral-directional augmented effects, both in landing and up-and-away, is needed. Data comparing ground-based and in-flight simulators are also needed so that the respective roles of the analytical and experimental tools currently used for flight control system design are brought into perspective.

PLANNED ANALYSIS FOR EQUIV. SYSTEM SIMULATION

- o EQUIVALENT SYSTEMS -
  ANSWER BASIC QUESTIONS
- o MIL-F-8785 COMPARISONS
- o K/S OPEN LOOP CORRELATIONS
- o PILOT-IN-LOOP:
  - o NEAL & SMITH
  - o MCPILOT (PAPER PILOT)
- o FFT
- o PUBLICATION. PRELIMINARY ANALYSIS . . .

FIGURE 1

LONGITUDINAL

NAVY FIGHTER RESULTS ON

- o BASIC EQUIVALENCE
- o L_α FIX - FREE
- o MISMATCH THRESHOLD
- o TIME DELAY EQUIVALENCE

CONFIG	HOS/LOS	ζ/ω	L_α	ξ	MIS MATCH	RATING
	HOS					2
1	LOS	1.0/1.4	.5	.14	40	2
	LOS	.6/3.5	6.3	.09	20	3
	HOS					3
2	LOS	1.5/1.7	.54	.14	20	3
	LOS	.7/5.3	12.0	.08	.7	4

FIGURE 2

LONGITUDINAL

DELAY EFFECTS

$\zeta = .57$

$\omega = 2.3$

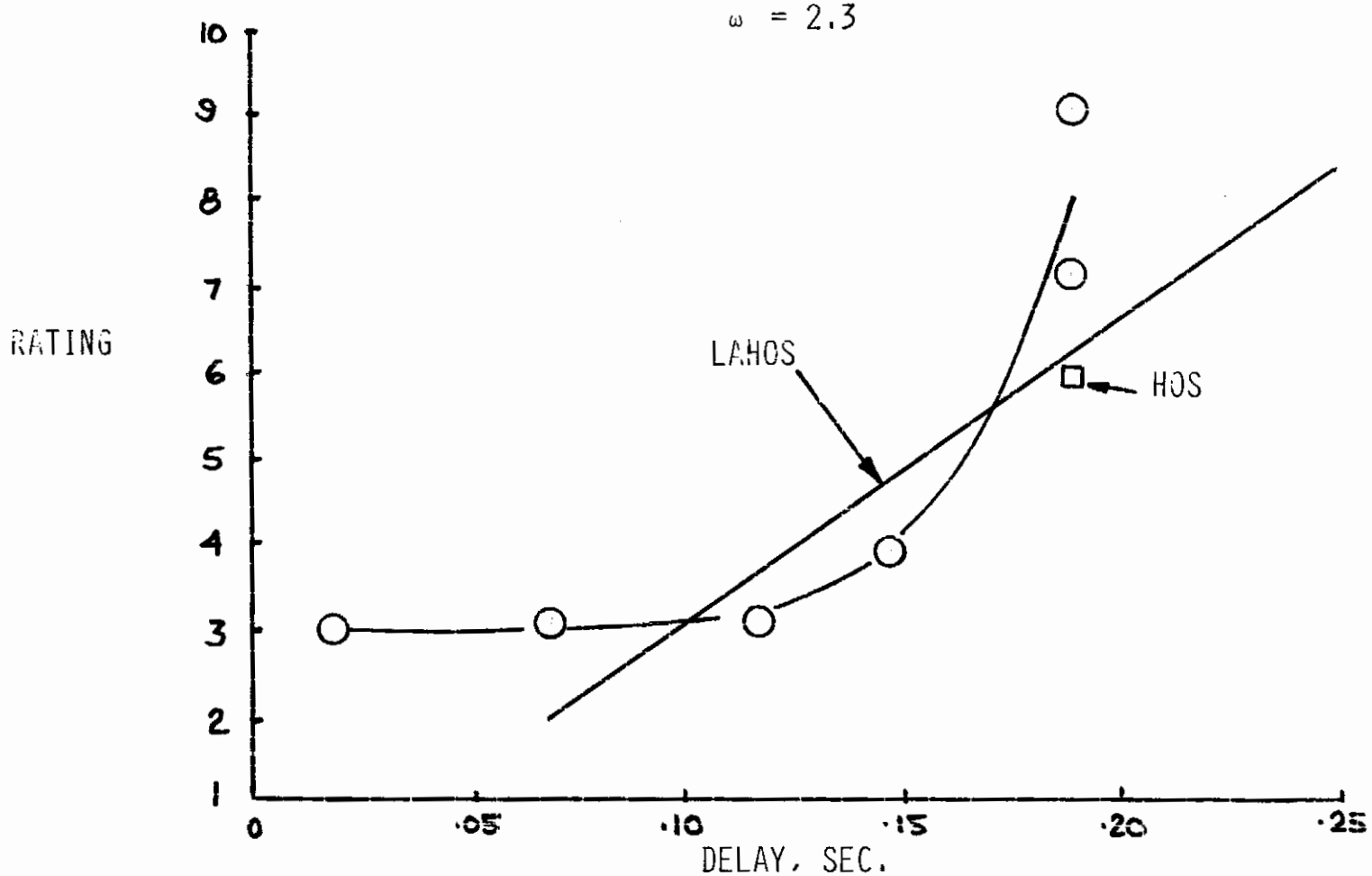


FIGURE 3

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LATERAL

NAVY FIGHTER RESULTS ON:

- o BASIC EQUIVALENCE
- o TIME DELAY EQUIVALENCE

CONFIG	HOS/LOS	τ_R	DELAY	RATING
1	HOS			4
	LOS	.44	.15	3
2	HOS			4
	LOS	.37	.13	4, 3

FIGURE 4

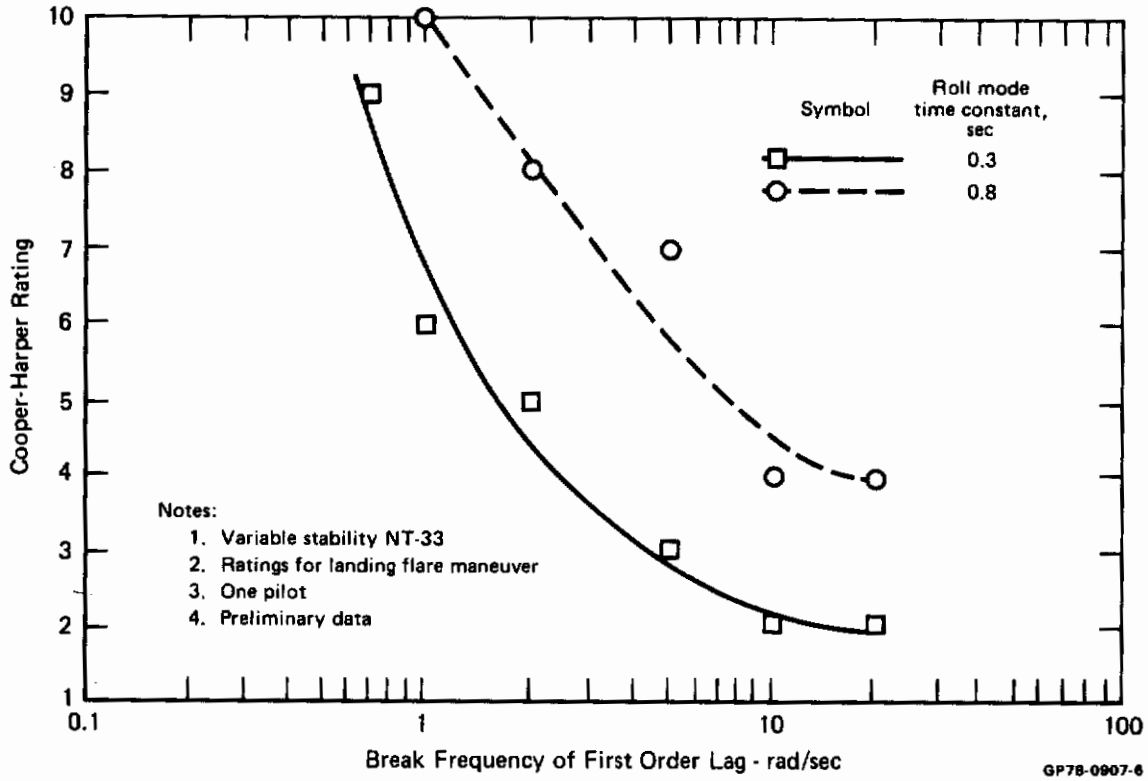

FIGURE 5

EFFECT ON PILOT RATING OF FIRST ORDER LAG IN LATERAL RESPONSE

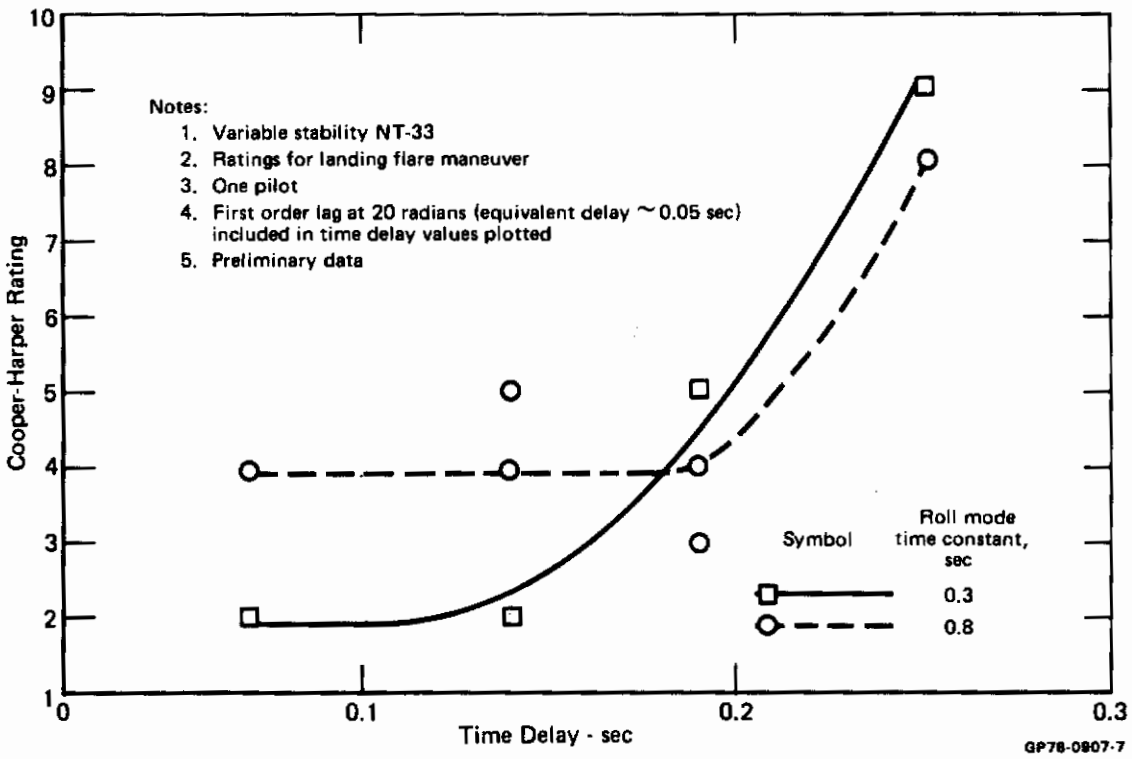

FIGURE 6

EFFECT ON PILOT RATING OF TIME DELAY IN LATERAL RESPONSE

SUBEXPERIMENTS

LONGITUDINAL

- o EQUIV. SYSTEMS FOR LAHOS
- o FEEL SYSTEM $\stackrel{?}{=}$ DELAY
- o GAIN EFFECTS
- o LEAD COMP. OF DELAYS

LATERAL

- o .63 (TIME RESPONSE) $\stackrel{?}{=}$ TIME CONSTANT

EXPLORATORY

PRELIMINARY

FIGURE 7